STATISTICAL RELATIONSHIP BETWEEN VEHICULAR CRASHES AND HIGHWAY ACCESS

INTRODUCTION

The Minnesota Department of Transportation has undertaken a variety of new initiatives in an attempt to improve traffic operations and safety on the States 12,000-mile Trunk Highway System. One of the initiatives authorized by the legislature involves developing a process and a set of guidelines to take a more proactive approach to managing access from abutting properties.

In order to inform the legislature of the potential impacts of access management, Mn/DOT has studied the legal issues associated with property rights and local land development regulations. In addition, Mn/DOT retained the services of BRW, Inc. to assist with conducting a traffic safety study to help determine to what extent a case can be made for suggesting that access management is a public safety issue.

Mn/DOT was aware of the potential safety implications of access management as a result of previous research. However interesting this data appeared to be, Mn/DOT did not consider the information conclusive because the reports either did not actually document access density, did not consider different roadway types or the data was based on a very small sample size.

Mn/DOT placed a very high priority on having this study produce credible results with a very high level of statistical reliability. However, during the initial phase of the study it was determined that the data collection efforts associated with a analysis of the entire State Highway system was beyond Mn/DOT's time frame and budget. Therefore the study focused on first identifying and then analyzing a random and statistically representative sample of roadways.

The key steps in the study process are listed below and then described in more detail in the following sections:

- Data Collection
- Document and Analyze Access and Crash Statistics
- Analyze Relationship with Traffic and Roadway Characteristics
- Review Minnesota and Iowa Case Studies
- Conduct Statistical Tests
- Calculate Expected Benefits vs. Costs

In summary, the purpose of this project is to provide a comparison to the results of previous access management research conducted elsewhere and then based on comprehensive analysis of Minnesota access and crash statistics, determine if access management is a legitimate public safety issue.

DATA COLLECTION

Category Selection

The first step in developing this project was to determine the different roadway classifications that would be analyzed for the effect of access on the crash rate. The Minnesota Department of Transportation categorizes its roadways based on five parameters, including, roadway environment (rural, suburban, or urban), roadway design (conventional, expressway, or freeway), number of through lanes, type of median treatment (none or median), type of left turn treatment (none, paint, and physical). Breaking this down, there are 162 possible description combinations for a roadway in the State of Minnesota. Although many of these combinations are not used this was still too large a number of roadway types to analyze and some sort of consolidation was necessary.

The important factor in consolidating the different types of roadways was to come up with a manageable number of homogenous roadway categories that isolate the effects of access characteristics. As a result, eleven different roadway categories were selected for analysis. These roadway categories are listed in Table 1 along with a short definition of the category and an alpha descriptor. The alpha descriptor shown for each category in this table will be used in the rest of this document as an abbreviation for the category definition.

TABLE 1
ROADWAY CATEGORIES

NO.	DESCRIPTION	ABBREVIATION
1	2-Lane Rural Conventional/No Left Turn Lanes	RC2NLT
2	2-Lane Rural Conventional/With Left Turn Lanes	RC2LT
3	4-Lane Rural Conventional	RC4
4	6+Lane Rural Conventional	RC6
5	4-Lane Rural Expressway	RE4
6	2-Lane Urban Conventional/No Left Turn Lanes	UC2NLT
7	2-Lane Urban Conventional/With Left Turn Lanes	UC2LT
8	4-Lane Urban Conventional/No Left Turn Lanes	UC4NLT
9	4-Lane Urban Conventional/With Left Turn Lanes	UC4LT
10	6+Lane Urban Conventional	UC6
11	4-Lane Urban Expressway	UE4

Segment Selection

The definitive study of Mn/DOT's road system would have involved sampling all 4,645 segments and 10,868 miles of conventional roads and expressways in the state. However, this magnitude of data collection was considered beyond the scope of the project and therefore it was determined that a statistically reliable randomly selected sample was sufficient for this project. A preliminary investigation suggested that a minimum total of 500 crashes in each category and a minimum of 25 segments should provide statistically reliable results.

Using the criteria described above a sampling percentage of the total number of segments in each category was determined. This percentage combined with a randomly generated seed applied to the total population of each roadway category then determined the segments that were to be sampled. Table 2 shows the size of the study sample and the statewide population for each of the roadway categories. This table shows that the sample set includes 432 segments and 766 miles of roadway.

TABLE 2
STUDY SAMPLE

	STATEWIDE POPULATION		STUDY SAMPLE	
CATEGORY	SEGMENTS	MILES	SEGMENTS	MILES
RC2NLT	2,710	9,020	120	412
RC2LT	14	20	14	20
RC4	79	142	36	68
RC6	7	7	7	7
RE4	202	577	25	80
UC2NLT	1,166	702	58	38
UC2LT	28	20	20	14
UC4NLT	130	83	48	29
UC4LT	112	83	42	33
UC6	28	26	17	14
TOTAL	4,645	10,868	432	766

Access Data Collection

The most labor intensive and time consuming piece of data to collect was the number of access points in each segment. This information was obtained through viewing the video logs the Minnesota Department of Transportation keeps for all its state highways. The data collection involved scrolling through 766 miles of state highway in order to account for approximately 9500 access points.

The access points were broken down into five different types of access including, public streets, commercial driveways, residential driveways, field entrances and other accesses (access points that could not be identified). The convention that was used for determining the number of accesses involved simply counting the number of intersecting legs with the main roadway. Therefore a T-intersection with the main roadway would constitute one access point and a 4-leg intersection with the main roadway would constitute two access points. It should be noted that the counting of accesses was not affected by whether or not the access point had full access (i.e. open median) or partial access (i.e. closed median).

This counting convention was selected after checking with other researchers at the Federal Highway Administration and Iowa State University. It was determined that this counting convention was consistent with the methodology in other similar research studies.

Crash Data Collection

The crash data used in the analysis of the sample segments was obtained from the Minnesota Statewide Crash Database. The collected data accounted for 13,700 crashes on all the sample segments between the years of 1994 and 1996 and included, total number of crashes, crash rate, total number of crashes for each level of severity (Fatal, Personal Injury A, B, and C, and Property Damage) and categorization of crashes by type of crash.

Segment Data

The segment characteristics for each sample segment were obtained from the Minnesota Roadlog Database. The following segment characteristics were obtained for each individual segment sampled:

- Segment Length (miles)
- Segment ADT (Average Volume across segment from 1994-1996)
- Segment VMT (Vehicle Miles Traveled from 1994-1996)
- Speed Limit
- Segment Environment (Rural, Suburban, Urban)
- Segment Design (Conventional, Expressway, Freeway)
- Number of Through Lanes
- Median Treatment (none or median)
- Left Turn Treatment (none, painted, physical)

TECHNICAL ANALYSIS

The focus of the technical analysis was to document the crash statistics as a function of access density for each segment in each roadway category, identify any observed trends in the data and then to provide an initial assessment of the relationship between access density and crash rate.

Roadway Access Statistics

The statistic used throughout this project to describe the level of access on a segment of roadway is access density. Access density is simply the average number of accesses per mile. It was computed by taking the total number of accesses in each segment that was sampled and dividing by the length of the segment.

It was determined that the average access density for all rural categories is approximately 8 accesses per mile and the average access density for all urban categories is approximately 28 accesses per mile. The data also shows that for similar types of roadway categories the urban category always has a higher average access density than the rural category.

The data also shows that residential driveways (38%) are the most prevalent types of access in rural areas followed by public roads (28%). Public roads (40%) are the most prevalent types of access in urban areas followed by commercial driveways (34%). This data suggests that the greatest opportunities to manage access involve public streets and residential driveways in rural areas and public streets and commercial driveways in urban areas.

Crash Statistics

The statistic used throughout this project to describe the level of crashes on a segment of roadway is the crash rate. Crash rate is simply the number of crashes per million vehicle miles traveled. The number of vehicle miles traveled is calculated from the segment ADT, the segment length, and the period of time over which the crashes were observed.

The average crash rates for the sample segments were first compared with the statewide average crash rates by roadway category. This analysis found that the crash rates for the sample segments are very similar to the crash rates of the statewide population. The data also shows that urban roadways have significantly higher crash rates than rural segments with similar design features.

Additional analysis of the crash data found that there are significantly more single vehicle crashes on rural roadways than on urban roadways and that the percentage of fatal crashes on rural roadways is three times the percentage on urban roadways.

Roadway Access/Crash Rate Relationship

As stated in the introduction, previous research suggests a positive relationship between access density and crash rate. Theoretical reasoning that suggests an increase in crash rate as access density increases supports this premise. This reasoning is based on the belief that turning vehicles and the conflicts caused by these turning vehicles is a major cause of crashes. In addition, this line of reasoning also suggests that with more access points, the number of possible conflict points increase and as a result the crash rate would be expected to increase as well.

The crash rate/roadway access relationship is documented in Table 3 for each of the eleven roadway categories, as a function of the different levels of access density.

This data shows that in almost every category there is a strong positive observed relationship (increasing crash rate as access density increases) between access density and the crash rate. This relationship doesn't always appear between the different access density groups but it does always exist between the highest and lowest levels of access. Another interesting relationship was noticed when the average access density for each category was compared to these figures. In most cases the access density groups with crash rates lower than the category average also had access densities that were lower than the category average. The reverse was also true as most access density groups with crash rates higher than the category average had access densities higher than the category average.

TABLE 3
SAMPLE SEGMENT CRASH RATES AS A FUNCTION OF ACCESS DENSITY

RURAL ROAD	ACCESS DENSITY (ACCESSES PER MILE)				STATEWIDE AVG. CRASH RATE
CATEGORY	0-5	5-10	10-15	+15	
RC2NLT	0.8	1.0	1.3	1.3	1.1
RC2LT			1.8	2.1	1.9
RC4	0.9	1.1		2.8	1.2
RC6		4.4		2.8	3.4
RE4	0.6		0.8		0.8
URBAN ROAD					
CATEGORY	0-10	10-30	30-50	+50	
UC2NLT	1.7	2.6	4.9	6.0	3.2
UC2LT	3.0	3.0	5.3	5.2	4.3
UC4NLT	2.2	3.3	4.7	7.4	5.3
UC4LT	2.6	4.5	5.6	10.4	4.6
UC6	3.6	4.7	8.7	4.2	6.5
UE4	1.6	2.4		6.0	2.0

Additional technical analysis was also conducted to see if the observed relationship between access density and crash rates could be the result of other variables, such as traffic volume, traffic speed, or related to the type of access (public street, commercial driveway, etc.). To test the effect of traffic volume, crash data was tabulated by traffic volume category. The results of this effort found crash rates to be consistent across each of the volume categories and this suggests that traffic volume does not effect the access density/crash relationship.

In an effort to understand the effect of traffic speed, crash data was tabulated by traffic speed category. Only data for urban roadways was analyzed because there was no variance of speed limits on rural roadways, all of the rural segments had 55 mile per hour limits. The results of this effort shows a strong negative observed relationship between speed limit and crash rate, the crash rate decreased as the speed limit increased.

Analysis was also conducted to determine if the type of access had any effect on crash rates. This analysis consisted of plotting crash rates as a function of the density of particular types of access. The results suggest that in rural areas, the positive observed relationship between access density and crash rate does not appear to be a function of any particular type of access. However, in urban areas it does appear that the observed relationship between access density and crash rate is primarily a function of public street and commercial driveway access.

The results of the technical analysis suggest that a strong positive relationship (crash rate increases with increasing access density) was observed between access density and crash rate.

CASE STUDIES

The technical analyses documented in the previous section focused on the observed relationship between access density and crashes along a sample of Minnesota roadways. This section approaches the safety issues associated with access management from a second perspective, actual before/after case studies for three projects in Minnesota and eight projects in Iowa. The case studies consisted of documenting the following project related information:

- General project description
- Before and after traffic volumes
- Before and after crash frequency
- Before and after crash rates
- Before and after access density (where data was available)
- Results

Minnesota Case Studies

The three roadways included in the Minnesota Case Studies included TH 49 (Rice Street), TH 3 (Robert Street) and TH 61 (Vermillion Street). All of the roadways are in suburbs surrounding the St. Paul-Minneapolis metropolitan area and all were experiencing significant safety problems. These roadways are classified as urban arterials with 30 or 35 mile per hour speed limits and daily traffic volumes ranging from 15,000 to 25,000 vehicles per day. Prior to the implementation of the reconstruction projects, each of the roadways had significantly higher than expected crash frequencies (more than 100 crashes per year) and crash rates (between 6 and 13 crashes per million vehicle miles).

The Minnesota projects, overall, were designed to address the safety deficiencies by reducing conflicts along each of the roadways. These projects include conversion of a two and four-lane undivided roadway to a three-lane road, conversion of a four-lane to a five-lane, and the addition of raised medians with protected turning bays to a four-lane undivided roadway. As a result of these projects, crash frequency and crash rates were reduced by an average of more than 40 percent.

Iowa Case Studies

The Iowa Case Studies were documented in a research report prepared by the Center for Transportation Research and Education at Iowa State University, as part of the Iowa Access Management Awareness Project. The Iowa Department of Transportation, Iowa Highway Research Board and the Federal Highway Administration funded this research project.

The eight roadways in the Iowa Case Studies are located in either the Des Moines metropolitan area or in regional centers around the state. All of the roadways are classified as urban arterials with lower speeds and daily traffic volumes in the range of 15,000 to 29,000 vehicles per day. Each of the roadways is also experiencing high crash frequencies and crash rates (between 5 and 9 crashes per million vehicle miles). The Iowa projects were designed to address the identified safety deficiencies by providing systems of left turn lanes, frontage roads and reducing the number of commercial driveways.

The results of the research from the Iowa Access Management Awareness Project showed that these access management projects had a significant, positive impact in terms of traffic safety. The average reduction in the density of access was approximately 20 percent and the reduction in annual crash rates was approximately 40 percent.

Summary

The crash reductions resulting from all but one of these eleven access management projects are significant at a 95% confidence interval. The only case study where the resulting crash rate reduction was not statistically significant is the Spencer (US 71) case study in Iowa. It is interesting to note that this case had the smallest crash reduction and the highest density of access after reconstruction.

STATISTICAL ANALYSIS

Statistical analysis of the data was a key component of this project to ensure the validity and reliability of the results about the relationship between access density and crashes. Consideration of statistical issues began with the initial random selection process of roadway segments. A randomly generated seed determined which segments would be sampled. This random selection process makes it likely that the samples are representative of the roadways in the state. This increases the probability of producing statistically reliable results.

Following the documentation of the crash rates for each of the roadway categories and the identification of an apparent access density-crash rate relationship, the data was subjected to a series of statistical tests. Within a roadway category, different segments may have different crash rates for a number of different reasons. Conclusions one may reach from a statistical analysis about the access density – crash rate relationship may be suspect unless other effects are found to be unimportant. Therefore, tests were performed to address these concerns.

One reason different sites may have different crash rates could be the dependency of the crash rate on traffic volume. A simple test of the correlation between ADT and Access Density was performed to address this concern. Low correlations were found for nine out of the eleven roadway categories. This indicated that the crash rates were not dependent on traffic volumes.

Another reason why segments within a category may have different crash rates could be because of unobserved differences among the segments. Therefore, a test was performed to check the variability of the observed crash rates within each of the roadway categories. The results indicated that the crash rates varied more than what would be expected (were overdispersed), thus posing problems for statistically reliable results. As a result, specialized statistical analysis was under taken to address the concern of the variability of the crash rates. This analysis would produce statistically reliable results for judging if crash rates tend to increase as access density increases, despite the variability found in the data. The results of this testing showed that, in five out of the six roadway categories that had large enough sample sizes, the crash rate tends to increase as the access density increases (a significant access effect was found).

Confidence intervals (90%) were also reconstructed for the six out of eleven roadway categories that had large sample sizes to produce statistically reliable results. This analysis found that five out of six categories showed a statistically significant difference in crash rates between the lowest access density range and the highest.

Table 4 presents a summary of the access density – crash rate relationship for each roadway category. A positive relationship was observed between access density and the crash rate (crash rate appears to increase as the access density increases) for ten of the eleven segments. Five out of six roadway types with a sufficient sample size to draw statistical conclusions were found to have a statistically significant access effect.

TABLE 4
SUMMARY OF ACCESS DENSITY – CRASH RATE RELATIONSHIP

Roadway Categories	Observed Positive Access/Crash Relationship	Adequate Sample Size for Statistical Analysis	Statistically Significant Access Effect
RC2NLT	✓	✓	✓
RC2LT	✓		
RC4	✓	✓	✓
RC6			
RE4	✓		
UC2NLT	✓	✓	
UC4NLT	✓	✓	✓
UC6	✓		
UC2LT	✓		
UC4LT	✓	✓	✓
UE4	✓	✓	✓

The statistical tests performed show that on a majority of roadway types with a sufficient sample size, there is a statistically significant tendency for sites with higher access densities to have higher crash rates in both urban and rural areas.

BENEFIT-COST ANALYSIS

An analysis was conducted in order to estimate the potential benefits (based solely on crash reduction) that could be realized from the implementation of access management projects.

Benefit-cost analysis looks at the benefits generated by a project and compares them to the cost incurred by the project over a certain analysis period. A project is generally considered economically feasible if the benefits are greater than the costs, producing a benefit-cost ratio greater than one. Typically, the benefits (cost savings) associated with transportation improvement projects may include delay savings, crash cost savings, operating cost savings, routine maintenance cost savings and environmental benefits. This study utilized only the benefits from crash reduction.

The benefits due to crash reduction were determined by first calculating the number of crashes per mile for each category of roadway and then applying an average crash cost using the statewide distribution of crash severity and crash cost values used by Mn/DOT (Property Damage Only = $2,700, Personal Injury = $30,500, Fatality = $500,000). The average annual crash cost per year per mile was then calculated for each category. Finally, values for a range of crash reduction varying from 10 to 80 percent were calculated for each roadway category.

The costs presented for managing access represent initial capital investments annualized over 20 years with a discount rate of 5 percent. Operations and maintenance costs are not included. A range of investment levels and crash reductions were used because it is not possible to determine at this time either the exact cost of an access management project or the exact reduction in crashes that would likely occur due to the level of investment in access management. However, the range of crash reductions (10 to 80 percent) and per mile costs ($100,000 to $2,000,000 per mile) should be sufficient to cover most rural and urban scenarios.

The key conclusion of this analysis is that for many of the assumed combinations of crash reduction and cost per mile for managing access, the benefits outweigh the costs. Crash reduction benefit-cost ratios over 1.0 exist in every roadway category. However, greater benefits for similar levels of investment accrue from crash reduction on urban roadways than or rural roadways:

- If a $500,000 investment was expected to result in a 40 percent reduction in crashes, (the average crash reduction as determined by the case studies), the crash reduction benefit-cost ratios range from 0.18 for a 2-lane rural conventional roadway with no left turn lanes to 3.25 for a 4-lane urban expressway.
- If a $250,000 investment was expected to result in a 40 percent reduction in crashes, the crash reduction benefit-cost ratios range from 0.37 for a 2-lane rural conventional roadway with no left turn lanes to 6.50 for a 4-lane urban expressway.

The results of this analysis have the potential to be used as a guide for assessing the cost effectiveness of different access management projects.

CONCLUSIONS

The previously published safety research has suggested a link between access and crash rates. However, this research either did not actually document access density, did not account for known differences in crash characteristics between various roadway types or the data was based on very small samples. In addition, none of the research used either access or crash statistics from Minnesota.

In order to address these potential deficiencies and to provide an analysis of local crash data, this study was completed, using a representative random sample of segments from Minnesota's State Trunk Highway System. The characteristics of the study sample included 432 roadway segments, 765 miles of roadway (out of a statewide population of approximately 11,000 miles), 9,545 access points and 13,700 crashes (over the three-year period 1994-1996). The roadway segments were then divided into eleven roadway segment categories (five rural and six urban) in order to isolate the potential relationship between crash rates and access density.

Based on the results of the technical analysis, it can be concluded that there is an observed positive relationship between access density and crash rates in ten of the eleven highway categories (i.e., higher levels of access density resulted in higher crash rates). Only the 6-lane category does not show this correlation and this may be due to the small number of segments in this category. Additional analysis of the crash data in each of the roadway categories revealed that in all cases, roadway segments with the highest crash rates have high levels of access density and segments with the lowest crash rates have low levels of access density.

A comprehensive package of statistical testing was performed. The results of this testing indicate that there were sufficient sample sizes in six of the eleven roadway categories to reach statistically reliable conclusions and there was a statistically significant access effect in five of the six categories. The statistical testing also suggests that the differences in crash rates are not related to either traffic volumes or traffic speed.

A Benefit Cost analysis was completed for each of the eleven roadway categories. The results are based on a range of estimated project costs and crash reductions and indicate that positive outcomes (a B/C ratio greater than 1) are possible in every category. However, the data also suggest that urban projects would likely result in greater crash reductions and therefore, greater benefits.

Crash data was analyzed from two different perspectives; a comparison of crash rates on a random sample of the State's Highway System and a Before/After comparison of crash rates from eleven case studies. The results from each approach suggest a strong and statistically sound relationship between levels of accessibility and crash rates.

The final conclusion addresses the key question identified in the Introduction. IS ACCESS MANAGEMENT A LEGITIMATE PUBLIC SAFETY ISSUE? Crash data was analyzed from two different perspectives; a comparison of crash rates on a random sample of the State's Highway System and a Before/After comparison of crash rates from case studies in both Minnesota and Iowa. The results from each approach suggest a strong and statistically sound relationship between levels of accessibility and crash rates. Therefore, the results of the various analyses suggest that yes; access management is a legitimate public safety issue.

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